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ABSTRACT

Diagrid structural systems are now widely used for tall buildings construction. This system can provide great efficiency and aesthetic value in structure. Until now, all the structures of diagrid systems had been designed with full triangulated members from the ground level to the top of the building. Unfortunately, with that design it will cause limited spacing for entrance at the ground level. To overcome this problem, vertical columns that are constructed at the ground floor and connected with diagonal members at upper levels are proposed. Different arrangement of the position of the vertical base columns will be employed: uniform arrangement, non-uniform but symmetrical arrangement and non-uniform and non-symmetrical arrangement. The objective of this research is to understand the behaviour of lateral displacements of the building and distribution of axial forces of the columns and diagrid members due to wind load that is applied to diagrid structures system without columns and with columns of different arrangement at the base of the building. In this study, the STAAD PRO finite element software was used to analyse the buildings models. Based on the result form the analysis, it shows that when the spacing between the base columns is further between each other, it will increase the lateral displacement of the structure. In this study, Model 3 is the optimum arrangement with 6.0m spacing and uniform arrangement of columns at base when compared to others modified diagrid models. The comparison of diagrid and modified diagrid structures shows the diagrid structure provides better lateral resistance and efficiency to the building. Besides that, the shear lag effect at bottom of the building between diagrid structure and modified structures were very different. This is because the shear lag effect at the base columns of modified diagrid structures was influenced by the spacing of corner columns, spacing of the internal columns and the uniformity of the column spacing.

ABSTRAK

Sistem struktur diagrid kini digunakan secara meluas untuk pembinaan bangunan pencakar langit. Sistem ini dapat memberikan kecekapan yang baik dan nilai estetika dalam strukturnya. Sehingga kini, semua sistem diagrid telah direka bentuk dengan anggota tiga penjuru dari aras bawah ke bahagian atas bangunan. Malangnya, dengan reka bentuk ini, ia akan menyebabkan laluan keluar masuk bangunan di bahagian bawah menjadi terhad. Untuk mengatasi masalah ini, dicadangkan tiang menegak dibina di aras bawah dan ia akan bersambung dengan anggota tiga penjuru di aras atas hingga ke tingkat teratas bangunan. Susunan tiang menegak yang berbeza telah digunakan iaitu susunan yang seragam, susunan tidak seragam tetapi simetri dan susunan tidak seragam dan bukan simetri. Objektif kajian ini adalah untuk memahami perilaku anjakan sisi bangunan dan pengagihan daya paksi tiang menegak serta anggota diagrid yang disebabkan beban angin yang ditindakkan terhadap sistem struktur diagrid tanpa tiang menegak dan dengan tiang menegak yang mempunyai susunan yang berbeza-beza di bahagian bawah bangunan. Dalam kajian ini, perisian STAAD.Pro telah digunakan untuk menganalisis model-model bangunan. Berdasarkan keputusan dari analisis yang dijalankan, ia menunjukkan jarak yang jauh di antara tiang-tiang menegak akan meningkatkan nilai anjakan sisi struktur. Dalam kajian ini, Model 3 dengan jaraknya 6.0m dan susunan tiang menegak yang seragam mempunyai susunan yang optimum berbanding dengan model-model diagrid yang didiubahsuaikan. Perbandingan di antara struktur diagrid dan struktur diagrid yang diubahsuaikan menunjukkan struktur diagrid mempunyai rintangan sisi dan kecekapan yang lebih baik. Selain itu, kesan ricih sulur di bahagian bawah bangunan di antara diagrid dan diagrid yang diubahsuai adalah sangat berbeza. Ini adalah kerana kesan ricih sulur pada tiang menegak struktur diagrid yang diubahsuai dipengaruhi oleh jarak di antara tiang penjuru, jarak di antara tiang tengah dan keseragaman jarak tiang..

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

m	-	Metre
mm	-	Millimetre
kN		Kilonewton
f	-	Shear Lag Ratio

CHAPTER 1

INTRODUCTION

1.1 Background of Research

A building is a permanent or temporary structure that has floors, walls, windows and a roof which is designed basically for residential, commercial or industrial purpose. While, the tall building defined as a multi-story structure in which the height of the building will create different condition in design, planning, construction and use. In the most countries tall building are called as high rise building.

There are a few factors that involves in development of tall building which are economics, aesthetics, technology and politics. In the late 19th century, early tall building developments were based on economic. But in the early 20th century, the tall buildings were built in terms of structural system by using steel rigid frame with wind bracing. Among of them are Woolworth Building in 1913, Chrysler Building in 1930 and Empire State Building in 1931. By time to time, the developments of tall building were produced based on economics demands, technology development, design trends and sustainability.

First tall building was built in Chicago in 1885 with 10 story of Home Insurance Building. In 1990s, the tall building began to develop in New York City. The highest building at that time was the 102 story Empire State Building. Besides that, tall building began to appear and built around the world. The Council on Tall buildings and Urban Habitat (CTBUH) have released a list "The World's Tallest Building" since 1885.

Table 1.1: Top 10 The World's Tallest Building

No	Building Name	City	Height (m)
1	Burj Khalifa	Dubai (AE)	2,717
2	Shanghai Tower	Shanghai (CN)	2.073
3	Makkah Royal Clock Tower	Mecca (SA)	1,972
4	One World Trade Center	New York City (US)	1,776
5	Taipei 101	Taipei (TW)	1,667
6	Shanghai World Financial Center	Shanghai (CN)	1,614
7	International Commerce Centre	Hong Kong (CN)	1,588
8	Petronas Twin Tower	Kuala Lumpur (MY)	1,483
9	Zifeng Tower	Nanjing (CN)	1,476
10	Willis Tower	Chicago (US)	1,451

Structural system of tall building can be divided into two categories which are interior structures and exterior structure. When the major part of the lateral load resisting system is located within the interior building, it is called as interior structure. The Burj Khalifa used "buttressed-core" and Shanghai Tower used "outrigger and super column" as their interior structural system. The Exterior structural system can described as the lateral load resisting system being located along the building perimeter. Diagrid system is one of the example exterior structural systems that are recently used. This is due to its structural efficiency and aesthetic potential provided by the unique geometric configuration of the system (Varsani *et al.*, 2015). This system will be discussed further in this study. The example of diagrid structures that are famous are shown in Figure 1.1.

Figure 1.1: Diagrid Building (a) Capital Gate Building (b) Alda Headquarters (c) Atlas Building and (d) Hearst Tower.

1.2 Problem Statement

The increasing of the urban population and the limited land that is available have caused more tall buildings to be built in cities. At the beginning, the function of tall building was focused on commercial office building. But now, it was built for residential and hotel. For tall buildings, there are many types of structural systems. Diagrid system is one of them and it has been widely used for tall building worldwide.

Diagrid structures can provide great efficiency in structure without vertical columns. This will give an advantage for the architect to design complex-shaped tall building. For example from rectangular or square form to tilted or tapered or perhaps a free form too. In terms of sustainable building, diagrid structural scheme can contribute to sustainable concepts by minimizing the use of steel.

Based on previous studies, the triangulated members were constructed from the bottom to the top of the building as their framework. With that design, it will cause limited access for entrance spacing at the ground level. The open space concept is the most suitable for ground level or lobby because it is very suitable for public area and it provides natural light during daytime. To solve this problem, an alternative solution that can be used in this study is proposed, which is a modified diagrid structural building where vertical columns are installed at the base while the diagonal member will be started at the upper floor to the top.

1.3 Objectives of the Study

This study was conducted to understand the behaviour and efficiency of diagrid structure system with column of different arrangement at the base of the building in terms of lateral displacements of the building and distribution of the axial forces of the columns and diagrid members due to wind load. The objectives of the study are as follows:

1. To determine the lateral displacement of building that incorporates diagrid systems with vertical base columns and without vertical base columns when wind load is applied.
2. To investigate the change of the axial forces distribution due to the introduction of the vertical columns at the base of the diagrid system.

3. To obtain the behaviour of the lateral displacement and shear lag of the columns and diagrid members of the buildings that incorporate diagrid structure with different arrangement of the vertical base columns.

1.4 Scope of the Study

In this project, there are three different building systems that were analysed as shown in Figure 1.2.The first building is a simple frame building while the second one is a diagrid building with full triangulated member from the ground level to the top of the building. The third building is the modified diagrid buildings that have vertical perimeter columns on the first floor that serve as the base of the building while the diagonal members begin at the floor above the columns to the top of building. The main objective of this study is to compare the efficiency of modified diagrid structures that have columns at their ground floor with full diagrid structures in minimizing the lateral displacement and shear lag due to wind load. Both gravity force and lateral load due to wind will be considered. The plan area of all buildings is 36m x 36m and the number of stories is 60 storeys. The storey height is 4.0m and 69^0 of triangulated member of the diagrid structures will be used for all members. Malaysia and Hong Kong wind speed were used to calculate the wind load. STAAD.Pro finite element software was used to analyse all the models. For modified diagrid structure with column at base, there are three different types of arrangement of the vertical base columns used for the analysis:

1. uniform spacing between the columns,
2. varying spacing between the columns but symmetrical arrangement of the position of the columns, and
3. varying spacing between the columns with non-symmetrical arrangement of the position of the base columns

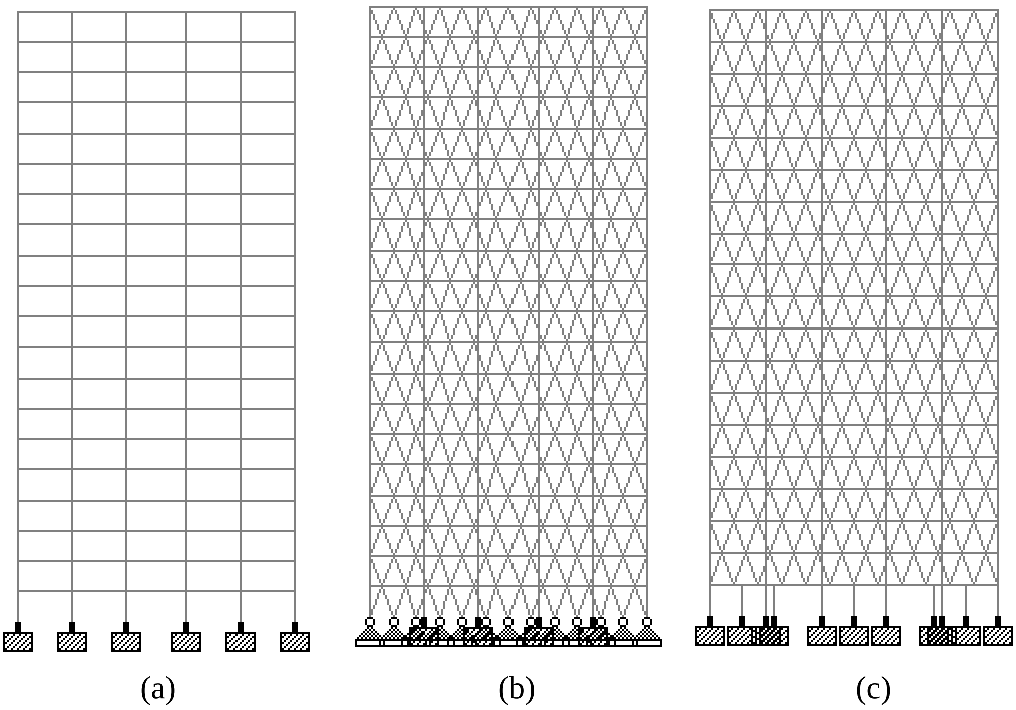

Figure 1.2: Building Models (a) Simple Frame Structure, (b) Full Diagrid Structure, (c) Modified Diagrid Structures with Vertical Base Columns

1.5 Importance of the Study

The increasing number of diagrid system used in the high rise building construction is due to the efficiency of the diagrid system to resist both gravity and lateral loads .Previous research proved that the gravity forces and lateral loads were transferred to diagonal member due to their triangulated configuration. Other than that, Moon (2014a) state that “this system will provide great structural efficiency and make the building more open space without vertical column”.

In this study, vertical base columns are introduced to the diagrid structure at its base and study is conducted to find out the structural response when wind load is applied to the building. This knowledge is very important for the structural engineers and designers especially during the early part of the design process of tall building. Comparisons in terms of lateral displacement and the distribution of the axial force for shear lag effect of diagrid structure and modified diagrid structures will be presented in this project

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